DOCUMENT RESUME

ED 121 306 IR 003 284

AUTHOR Feurzeig, Wallace; And Others
TITLE Higher Order Adaptive Training Systems. Final Report, May 1975-February 1976.
INSTITUTION Bolt, Beranek and Newman, Inc., Cambridge, Mass.
SPONS AGENCY Naval Training Equipment Center, Orlando, Fla.
REPORT NO NAVTRAEQUIPCEN-75-C-0104-4
PUB DATE Feb 76
NOTE 47p.

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage
DESCRIPTORS *Computer Assisted Instruction; Computer Programs; Diagnostic Teaching; *Educational Diagnosis; Error Patterns; *Flight Training; Instructional Systems; Instructional Technology; Learning Processes; Military Training; Protocol Materials; Simulation; *Simulators; Task Analysis
IDENTIFIERS *Adaptive Training; Flight Instructor Protocols; ORLY

ABSTRACT

Instructor diagnosis of pilot trainee errors was studied in the context of instrument flying using a computer simulation system called ORLY. ORLY was used to record student pilot runs on a number of instrument flying tasks. These runs were subsequently replayed to instructor pilots who diagnosed student errors and hypothesized the underlying difficulties. Analysis of these instructor pilot protocols will guide the design of computer-based diagnostic procedures to be incorporated in ORLY. (CH)

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Technical Report NAVTRAEQUIPCEN 75-C-0104-4

HIGHER ORDER ADAPTIVE TRAINING SYSTEMS

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

FINAL REPORT FOR PERIOD MAY 1975 - FEBRUARY 1976

February 1976

DoD Distribution Statement

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: NAVTRAEQUIPCEN 75-C-0104-6	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): HIGHER ORDER ADAPTIVE TRAINING SYSTEMS	5. TYPE OF REPORT & PERIOD COVERED: Final Report May 1975-February 1976
	6. PERFORMING ORG. REPORT NUMBER: 3220
7. AUTHOR(s): Wallace Feurzeig, George Lukas, and A.W.F. Huggins	8. CONTRACT OR GRANT NUMBER(s): NAVTRAEQUIPCEN 75-C-0104
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Bolt Beranek and Newman Inc. 50 Moulton Street Cambridge, Mass. 02138	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NAVTRAEQUIPCEN Task No. 4754-02P02
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Training Equipment Center Code N-215 Orlando, Florida 32813	12. REPORT DATE: February 1976 / 13. NUMBER OF PAGES: 39
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified / 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution is unlimited.	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)	
18. SUPPLEMENTARY NOTES	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Adaptive training Computer-aided instruction Flight instruction Simulation	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number): A computer-based instrument flight simulation system, ORLY, has been developed as the framework for an automated diagnostic and training facility. ORLY-based protocol experiments were designed in which student pilot difficulties shown in the course of carrying out IFR tasks were described and diagnosed by instructor pilots. Case studies of initial instructor protocols are described. Protocol analysis procedures and problems are discussed.	

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PREFACE

The work reported here has benefited from the contributions made by several persons skilled in computer science, flight instruction, and training technology. Dr. Dan Cohen, who developed the initial ORLY simulation system, consulted on the design of the compact GT-3 minicomputer version used in our experiments. He provided efficient algorithms for the clipping, windowing, and rotation programs used in the schematic world view display. Dr. Ira Goldstein has consulted on the problem of diagnosis of student pilot errors and in the design of a procedural model for skill acquisition in instrument flying. Dr. Victor Miller has consulted on the development of computer programs for error detection and diagnosis.

Three experienced instructor pilots, Laurie Cannon, Pat McHugh, and Marty Schiff, have been involved throughout. They are responsible for substantial improvements to ORLY, particularly the flight dynamics and instrument display facilities. They also provided essential assistance in detailed specification of student pilot tasks, selection of student pilot subjects, familiarization of student pilots with ORLY, and analysis of student pilot flight runs.

Mr. Don Norman of Naval Training Equipment Center (NAVTRAEQUIPCEN) Human Factors Laboratory made several useful suggestions regarding the design and layout of the ORLY instruments. Mr. Vincent J. Sharkey, scientific officer for the project, provided guidance on questions of experimental strategy, particularly as these related to integration of the work with other components of the program.

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Each SP that has been selected is well known as a student by an IP. Discussions with the IP provided profiles of the flying abilities and problems of the SP. Suitability for our experiment of subjects with extremes in experience was established. The novice IFR student was deemed interesting from a developmental point of view because of the expectation that she would be receiving instruction and acquiring skill at a substantial rate. The IFR-rated SP was accepted because, despite his considerable IFR experience, he had a number of problems that would be interesting targets for diagnostic study.

SP indoctrination on an experimental task comprises two parts. The SP's readiness for the task is established first. For example, if the task includes an ADF approach, the SP needs to be proficient in ADF tracking. Generally the SP is checked out on all prerequisite skills associated with the task. This is a necessary condition for readiness.

The other part of the indoctrination is an exposition of the task itself. A task is presented to the student as a written flight plan. The plan includes a sequence of flight procedures for execution, e.g., climb to 2000 ft. at 100 kts., level off at 2000 ft., cruise at 150 kts., etc. It also includes a flight map, a schematic plan view of the maneuver showing the ground track and possibly also a side view showing the altitude/time plot. The IP goes over the flight plan with the SP. He explains the procedures, discusses those aspects that might be difficult, and answers the SP's questions. When, in the judgment of the IP, the SP understands the plan, he is ready to proceed with the task.

The SP carries out the flight task in solo mode. The SP flight is recorded for subsequent replay. The ORLY flight recording program stores precisely those pilot's control inputs, the joystick and throttle positions, actually used to drive the ORLY flight dynamics and display programs during the pilot's run. Thus, during the replay, the SP flight is reproduced with perfect fidelity. Time plots showing ground track, altitude, and control excursion patterns during the flight are also generated on the GT-44 high-speed printer. Voice recordings of the SP's comments during the flight are produced on audio tape. The SP is asked to give a continuous narrative of his activity throughout, so long as he can do so without distraction from his flying. These recordings provide a source of back-up data; the primary source of data for IP analysis is the ORLY flight recording. Use of the SP flight recordings and the auxiliary time plot and voice recordings in the IP analysis is discussed next.

INSTRUCTOR PROTOCOLS

Each SP flight run record is analyzed by one or more IPs. The standard analysis procedure is the generation of a verbal protocol by the IP. This is a continuous verbal flow of his observations of the SP's performance as he sees the SP's flight being replayed on the ORLY screen. The ORLY instruments and schematic view are dynamically displayed exactly as these were shown to the SP. In addition, the IP's screen is augmented by a display of the SP's joystick control deflections. As he views the flight, the IP is asked to talk freely and steadily about the SP's actions, behavior, and difficulties in the course of the flight. The IP is told to speak without pause and to include everything that occurs to him. When he is silent for more than a few seconds, he is prompted to continue talking. He is permitted to stop the replay at points where he feels the need to collect his thoughts or to prepare for subsequent information-rich events. During these pauses he must also continue talking.

The kind of record produced by an IP verbal protocol is best shown by a concrete example. The following transcripts are taken from a routine IP protocol. The task is one of a series related to ADF approaches. It is briefly summarized by the IP at the start of the protocol.

> Marty Schiff analyzing playback of flight RD6B11. It's quarter of twelve and the first thing we're going to do is review the maneuver for my sake. The first phase of the maneuver is going to consist of taking off and climbing due north to the radio beacon at 1000 ft. per minute. The second phase is going to be making a 30° cut to the left, cutting down the rate of climb to 500 ft. per minute, starting the clock and doing that part of the tear drop for one minute. One minute defined as one minute on the simulator clock. The next phase of the maneuver starts at the end of one minute and is a standard rate turn to the right of 200°, and that phase of the maneuver should be level. The next phase of the maneuver involves intercepting and upon intercepting the rate of descent should be 500 ft. per minute. The maneuver is defined that from interception to the radio beacon should take one minute, going down at 500 ft. per minute. The next phase of the maneuver is from the radio beacon to the airport, southbound, and that should also be 500 ft. per minute. O.K. and that's as I remember the maneuver. I'm ready to start.

During the start of the flight the IP's comments are largely descriptive reportage. Even during this uneventful phase, he seeks to characterize the SP's understanding and planning behaviors.

> We're on the runway. The clock says 9 seconds and the power is coming up. We've just done a takeoff. Airspeed is hanging around stall. We have a positive rate of climb and good control movements and the heading is very good. The student is attempting to climb at 1000 ft. per minute but the best he can get is about 720-730. The radio beacon is dead ahead. Airspeed is just a little bit above one tick mark above stall and the wings are level and the power is full. There is very little useful information coming from the window and judging from this display the student understands just what's happening, and is just relaxing, waiting for the next activity to take place which is what he should be doing. We're going through the overcast, the time is 1 minute and 59 and about 1400 feet. We went through the overcast. Airspeed is rock steady, wings are level, the heading hasn't changed from triple 0's, and the ADF needle is pointing straight ahead.

The task becomes more challenging in the vicinity of the beacon during station passage. Note that the IP chooses to stop the action to anticipate the SP's upcoming problem and prepare for analyzing his handling of it.

> Six minutes and 25 seconds, the DME is 2.6, going through 6500 feet. The radio beacon is straight ahead and all the instruments that should be standing still are standing still. Coming up on the radio beacon, 2.7 on the DME, coming through 7000 feet, and we're about to get station passage. The ADF is acting up just like it would in a real airplane. And right now could we stop things? O.K. We just stopped the flight but the tape recorder is going. O.K. We are about to come across station passage and a lot of things are going to happen all at once, and we'll see how the pilot reacts to all of them. O.K. At station passage a turn of 30° to the left to 330 should take place and the rate of descent should go down to 500 feet per minute. O.K. so those two distinct things should happen. With a power reduction perhaps also happening, since no airspeed is being specified here. Not only that, it's very important that we note the time at the beacon passage, since we're going to be making an evaluation of what the student is doing. So for my sake, I want to write down the time and we should also be very aware of what happens at the passage, the turn, the rate of descent, and all of those things. The time right now is 6:51 and we are about to start playing again. O.K., now.

A little later, the SP should be starting his turn but has failed to do so. Again, the IP stops the flight to discuss this error.

The power is still pretty much full and the airplane is holding 330. We passed the beacon at 7:20 and it's now 8:46, and stop everything. A very common phenomenon took place here. The pilot was so busy going over the beacon that he forgot to write the time down. Now what he's doing is, the pilot knows from shooting these approaches on a regular basis how long it takes from the time that you make that 30° turn until the time that you finish the tear drop, and he's running on his own internal clock. If he were running on the clock on the computer display, he would know that at 8 minutes and 20 seconds he should start his turn back, his 200° turn at intercept. Now, judging from the way the pilot was flying, that's not the sort of thing that he would forget. It's now 8:53 and he still hasn't started the turn. 8:56 - 8:57 - 8:58. O.K., I'm going to tell you to stop as soon as he starts the turn. Not yet - now - stop. O.K., the pilot just started rolling into the turn and it's now 9:23. O.K., which is very interesting because it's exactly two minutes on this clock which is just about what a pilot would do if he were flying this on a regular basis. That would be, his normal clock is telling him to do it. The timing on this particular maneuver is not a critical time. It's only important that he stay within a 10 mile radius of the radio beacon. He's going through his own internal program which, again, doesn't seem like the sort of thing that this pilot would be doing. He doesn't have that internal program. So the pilot, even though he's an experienced pilot, and even though he understood this whole set of instructions that we went over, in spite of all that, he still made an error of 100 percent of this.

Toward the end of the run the IP needs to stop the action for his own sake, since he is momentarily confused.

We're in a right turn. This is a much more controlled turn. It's a standard rate turn. The airspeed is a little on the high side. You should start slowing down the airspeed now, and the attitude is level. And what should it be here? It should be level. He was doing a lot of things at once. Now the question is where does he roll out of the turn. 146 degrees. Well, can you stop it? I've got to sketch this out now. I lost track of what was happening. So I have to go through my own thought process. The radio beacon is north of the field and we went up and we're in left tear drop; coming out of a left tear drop, so that means that a proper intercept angle would have the ADF off

to the right, so this looks like a good intercept angle. The problem isn't with the intercept angle; the problem is with the airspeed. The algorithm specifies what the angle should be but it's superseded by the pilot in real time because he's got to adjust the intercept angle with the ADF and the descent. We should be doing 500 feet per minute going down, which is nice. And that's just what's happening and we're going right to the ADF.

The last phase of the run, the descent, as the first, is uneventful:

O.K., we're coming down now at 700 feet per minute. The radio beacon is behind us. Our heading is 180° and everything is going good. The pilot has reduced power. The clock is 13:25 - 13:28, and control deflection is good. The airplane is entirely under control. The ADF is behind and it looks like the pilot is attempting to make some minor corrections, but there are none really to be made. And it's about this time that the pilot would expect to become VFR.

: : :

In addition to verbal protocols, two other instruments were used to elicit IP diagnostic information: analytic summaries of SP flight runs and question-asking protocols. The use of these procedures is illustrated next in the context of a specific case study.

SECTION IV

CASE STUDY

The initial experimental work with SP subjects has mostly been done with a task that is accessible to students having basic IFR skills and yet is nontrivial for relatively advanced students. The task, in broad terms, is a take-off to an ADF approach. It involves a substantial VFR component and it imposed a significant cognitive challenge to most of our SPs. It provided a rich source of diagnostic data for testing and evaluation of various IP diagnostic procedures, particularly verbal protocols.

In this section a case study of an SP's flight on this task is presented. The SP flight chosen exhibits substantial errors due to cognitive problems. The flight run was made by the SP who was the most experienced of our subjects. While some SPs had virtually no difficulty in performing this task, this student had considerable difficulty. His previous flying

experience included a total of 270 flying hours, 135 hours of instruction time, and 55 hours of IFR flying. Also, he had recently obtained an IFR rating and he is currently working on an instructor's rating. Prior to his work on this task he had logged in two hours of familiarization time on OBJ5. This was deemed sufficient preparation for the task, despite some residual difficulties with ADF tracking. Because of the SP's experience, his instructor felt that he would work through his difficulties and gain some valuable learning from the experience.

The SP was given a written flight plan for the task comprising the following procedural description and associated maps. The procedural segments are labeled and the corresponding segments are marked on the two views of the maneuver map.

FLIGHT PLAN

For this exercise, take off, climb to 2000' and proceed direct to the NDB. After passing the NDB at 2000', time for one minute before starting a reversal (90 left, 270 right) and reintercepting the ADF course inbound. When passing the NDB inbound, descend at 500'/min. until airport is in sight, then fly visually and land.

All climbs - 100 kts.
All cruise portions - 150 kts.
All descents - 500'/min.
All turns at a standard rate.

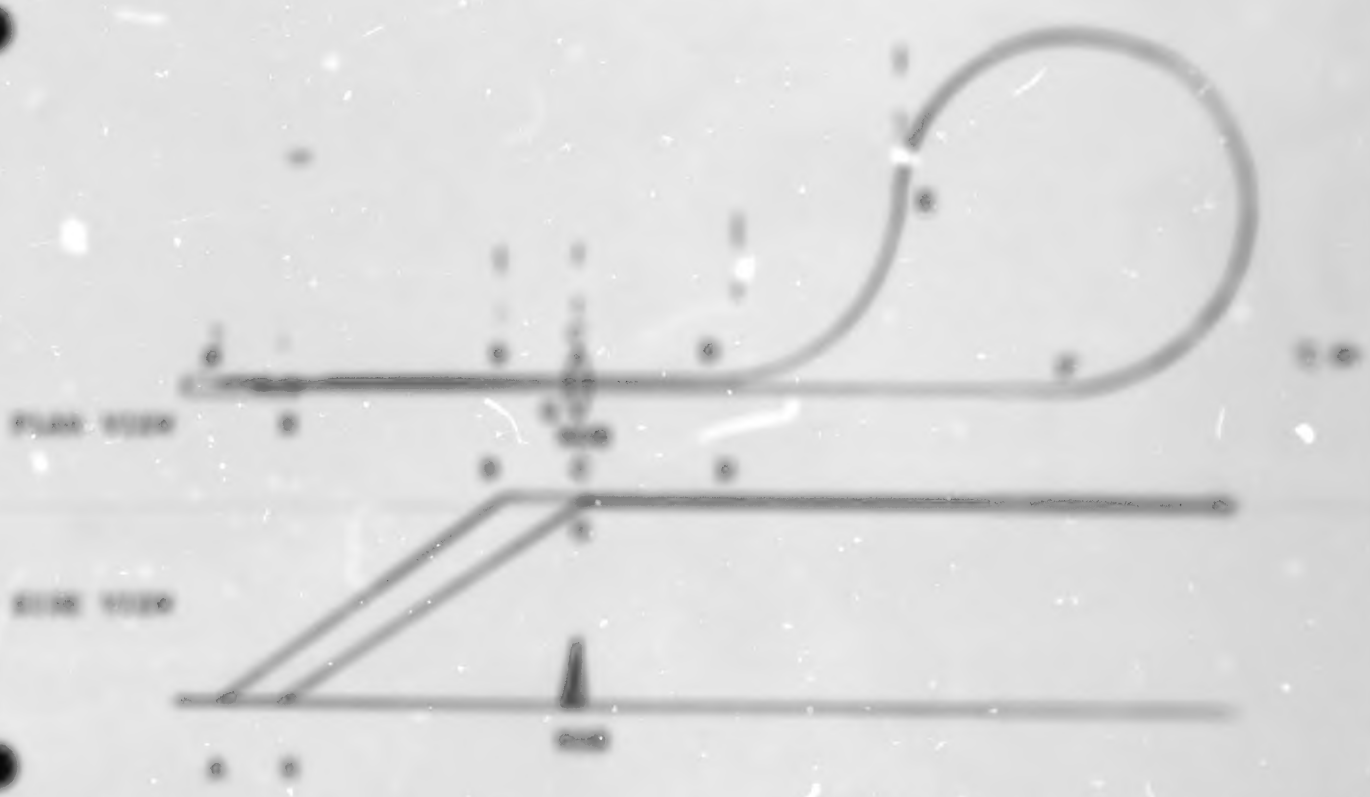

Figure 1. Maneuver Map

Segment	Procedure
A-B	Climb to 2000 ft. at 180 kts.
B	Level off at 2000 ft., execute at 150 kts.
C	Pass over beacon.
C-D	1 minute.
D-E	90° standard rate turn left.
E-F	270° standard rate turn right.
F-G	On-course/eight approach path.
G-H	Descend at 500'/min.
H	Land.

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Differential pattern-matching techniques may provide a basis for a computer-based error detection model which is similar in effect to this aspect of IP analysis. The diagnostic methods used by IPs in making inferences from observed errors to hypotheses about underlying conceptual difficulties remain the object of further work.

SECTION V

TASK ANALYSIS

In further work, we plan an extensive series of protocol experiments centered on a variety of holding patterns and approach maneuvers. In preparing for these experiments, detailed task specifications, systematic SP indoctrination procedures, and preliminary diagnostic forms are being designed. The following material on holding pattern maneuvers is illustrative of the background materials required for each task.

HOLDING PATTERNS

Student Pilot Instructions. This exercise is based on a standard holding pattern entry. We will orient you in different positions around the holding fix (VOR) and have you take off, climb to 2000' altitude, and enter the holding pattern. Here are a few things to keep in mind.

a. Standard holding requires right-hand turns in the pattern.

b. Always hold inbound on the radial to the fix.

c. The 70° arc is rotated to the holding side and divides the holding space into two sectors. Then the extension of the holding radial (line 3) divides the west sector into two parts.

d. If you are within 10° of the sector dividing line, use either entry.

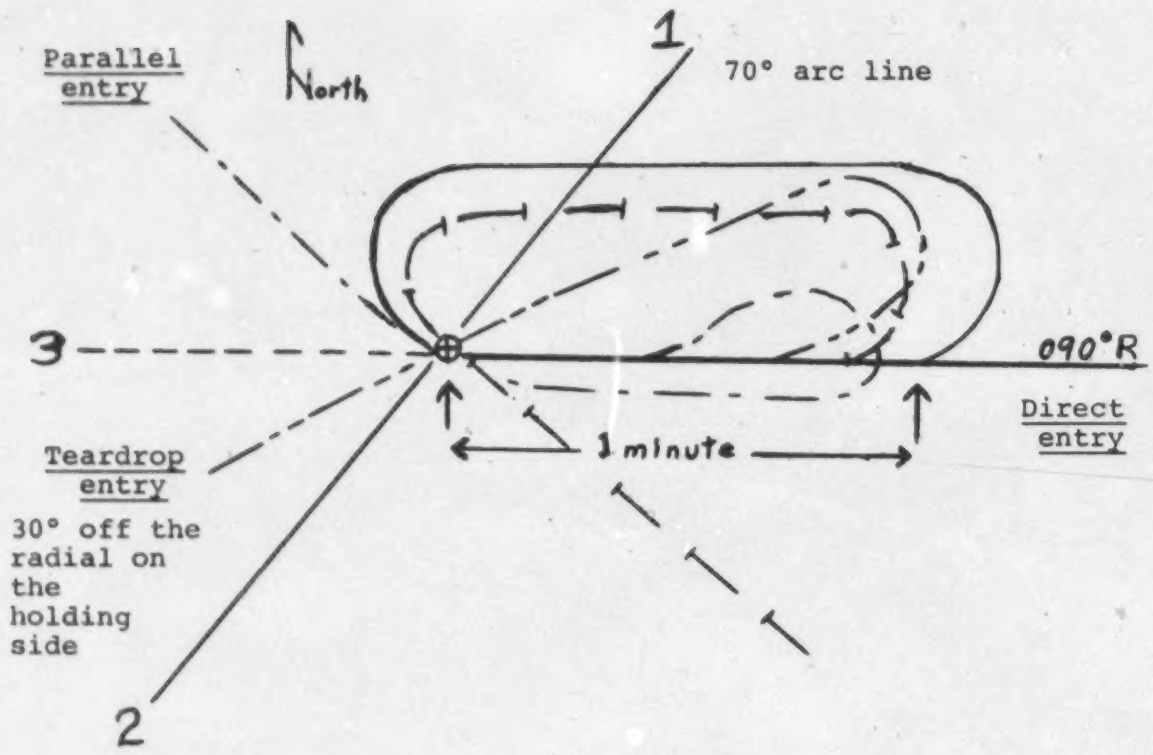

Figure 6. Holding Pattern Entries.

Holding Instructions. Hold east on the 090°R; right turns; one minute legs.

Student review questions before the start of the procedure.

a. Are you familiar with a standard holding pattern and its entries.

b. If so, explain what you would do when you get to the holding fix and are set up for a 1. Parallel entry
2. Teardrop entry
3. Direct entry.

c. Are you familiar with what the wind would do to you in a holding pattern?

d. If so, explain how you would vary your pattern with a wind from the North
South
East
West.

ORLY Orientation.

All take offs and climbs - full power and 100 MPH IAS.
All level offs and cruise - power as necessary and 150 MPH IAS.
Standard rate turns always.

a. Fly a pattern which covers climbs, descents, turns, A/S changes, and timing. Each straight leg should be one minute long.

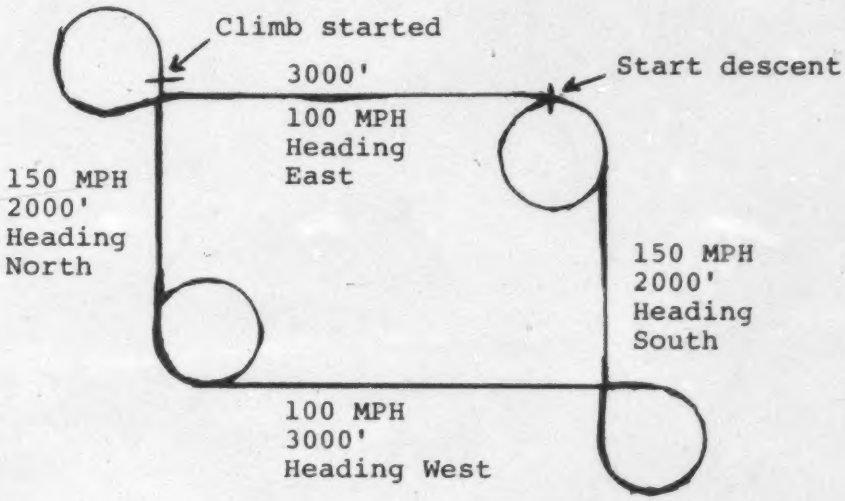

Figure 7. Map of Exercise a.

b. For navigation orientation proceed direct to the VOR and then track outbound on a radial that is not aligned with the inbound course by about 60°. Then proceed for a minute and do a procedure turn to the left.

Figure 8. Map of Exercise b.

Entry Patterns. The following diagrams are holding entries obtained from approaching a fix from two headings which produce a direct entry.

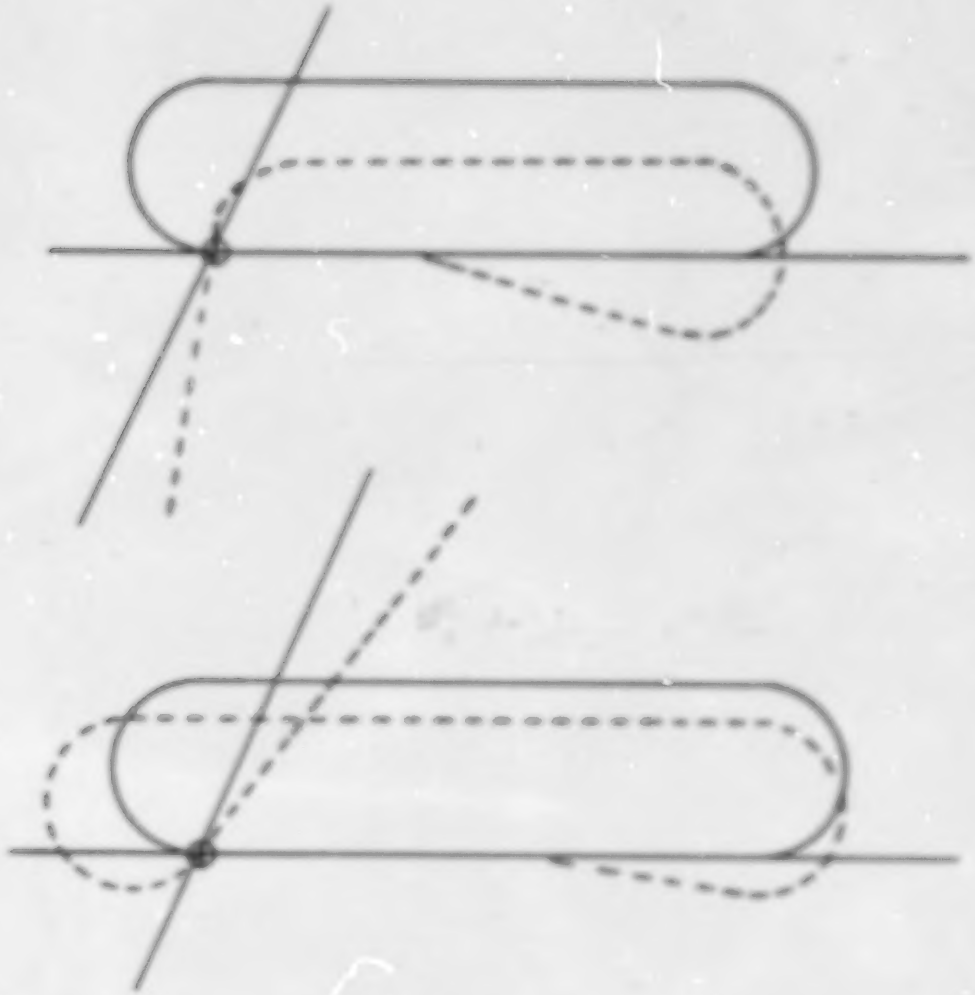

Figure 9. Direct Entry Patterns.

In both these direct entries we find that an overshoot of the radial when turning inbound is inevitable. Therefore, we must know that this is likely and when turning inbound be prepared to overshoot and also to take a 15° to 30° intercept angle on the radial. All entries in between these two are the same but with a lesser degree of overshoot.

Shown below are holding entries from two directions which produce a parallel entry.

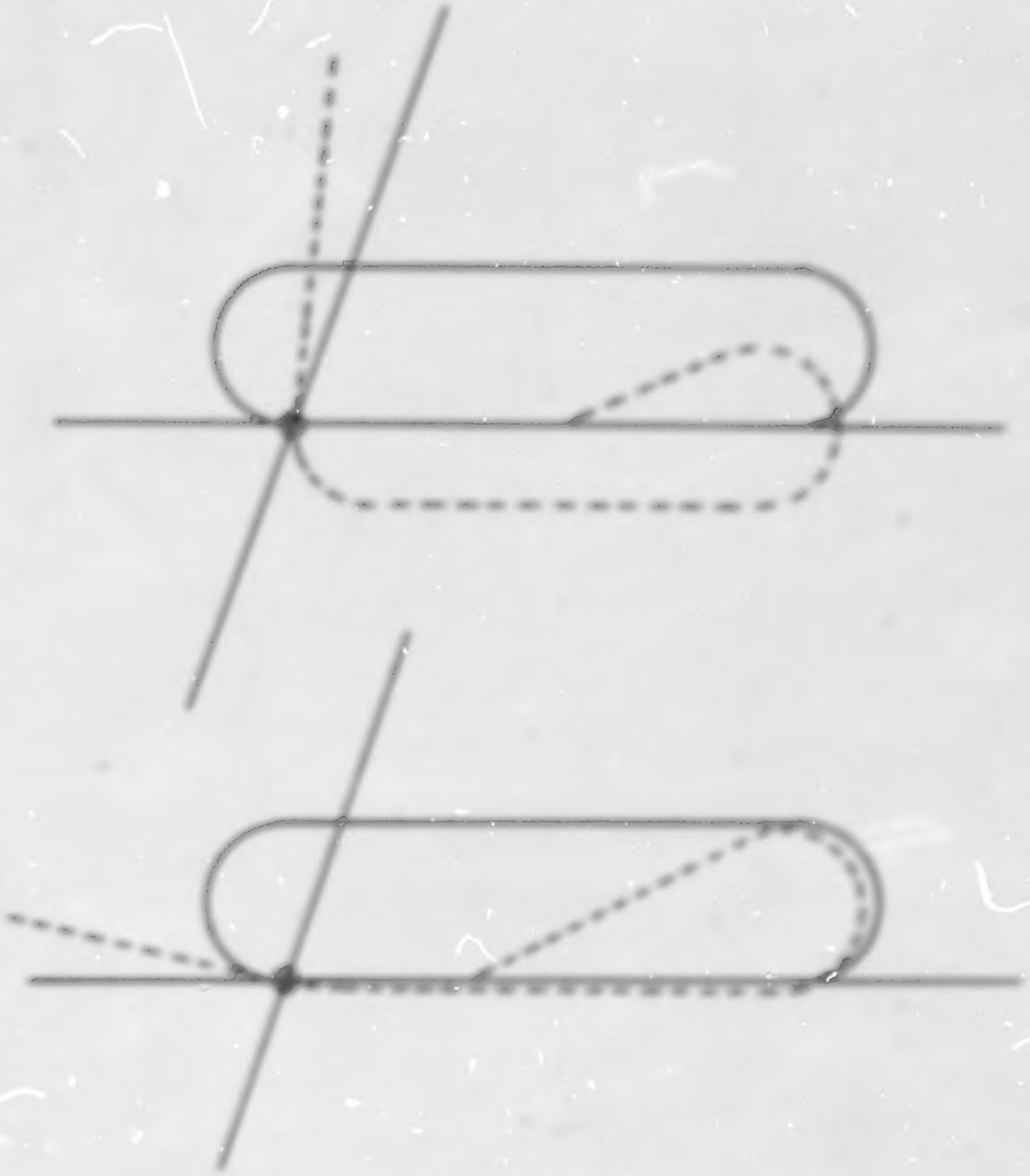

Figure 10. Parallel Entry Patterns.

The learning curve is shown below. (It is probably the easiest skill and probably causes the least change of [illegible].)

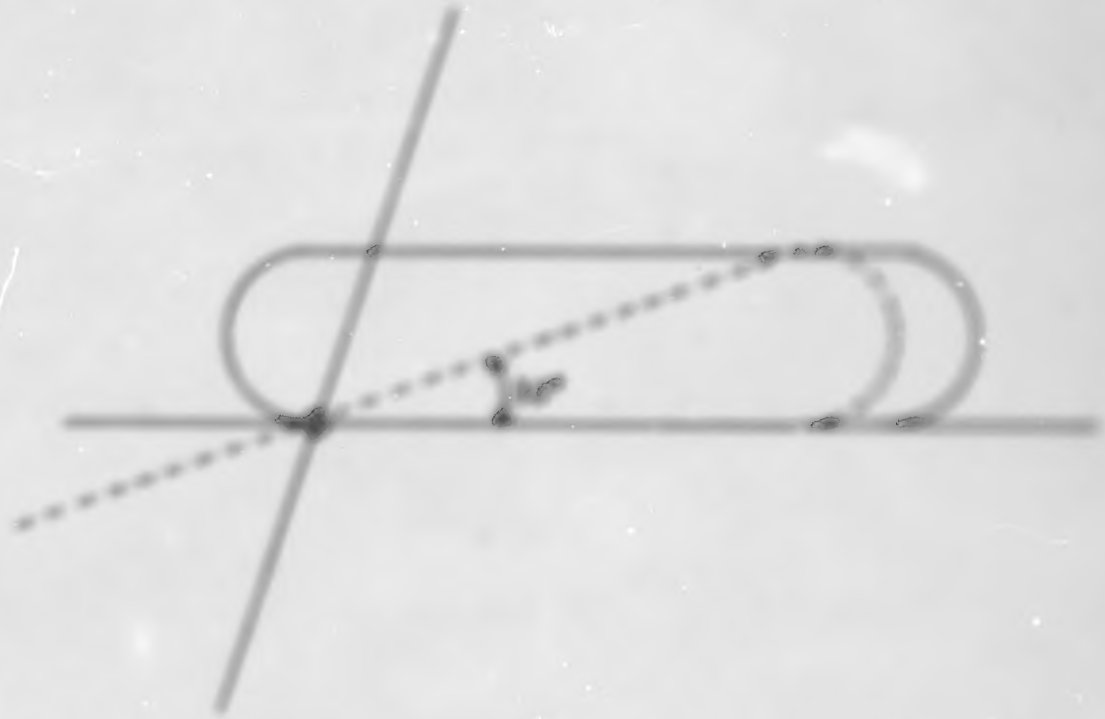

Figure 11. Learning delay factors.

Students experience the greatest difficulties with learning patterns in the planning and execution of aggregate groups. The other major source of difficulties in learning learning patterns is in sideways [illegible] and execution of eye [illegible].

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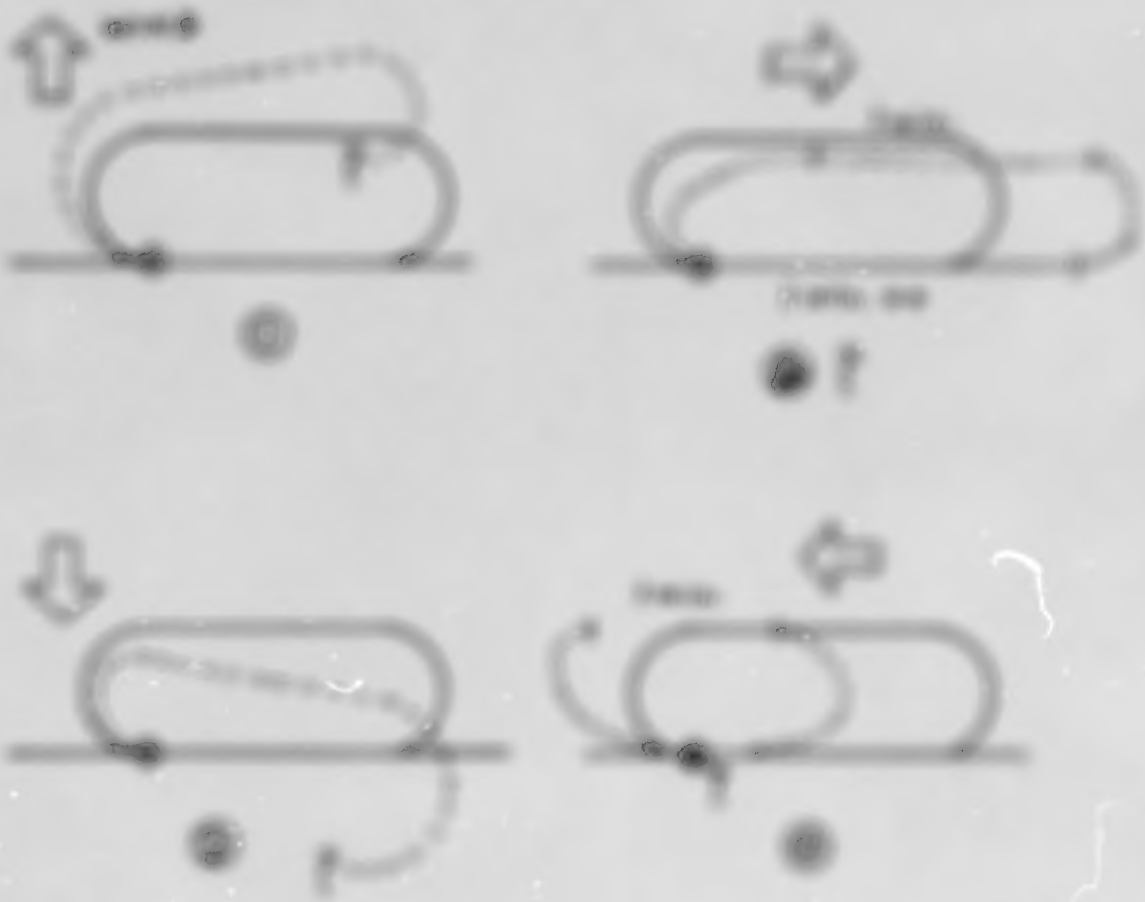

Figure 11. [redacted]

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SECTION VI

DIRECTIONS FOR FUTURE WORK

The development of diagnostic capabilities in ORLY will be furthered through a logical continuation of the task analysis and analytic modeling efforts described above. Specifically, we plan during the next months, to carry out the following developments.

a. Perform detailed analyses of the series of holding pattern tasks, which will serve as primary maneuvers for initial diagnostic study. These task analyses will include structured descriptions of skill components, performance errors, and learning difficulties. This analysis has already been started along the lines indicated above.

b. Collection and analysis of protocols of ORLY student pilot flights on the series of holding pattern maneuvers. As before, verbalization and retrospection will be augmented with question-asking. The protocol analysis work will provide our primary knowledge source for characteristic student errors and learning difficulties.

c. Top-down and bottom-up procedural models for analysis of student flights will be developed and elaborated for use with the holding pattern maneuvers. The preceding task analysis and protocol analysis will provide the knowledge base for this modeling work.

d. The procedural models will be implemented as the core of a system of computer-based programs for error detection and diagnosis. These programs will scan actual flight data, search for deviations from flight plans, and characterize student errors.

e. Testing and development of the diagnosis programs will be accomplished iteratively. Trials with actual student pilot flight data will lead to successive refinement of the programs.

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